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Assessment of the Impacts of Plant Growth-Promoting Micro-Organisms on Potato Farming in Different Climatic Conditions in Morocco

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Abstract: Environmental concerns are gradually reducing the global yield capacity of agricultural systems, with climate change representing the most significant challenge. Globally, Potatoes are the most essential non-cereal crop. Therefore, understanding the potential impacts of climate change on potato production is crucial for maintaining future global food security. This study aims to explore the roles played by PGPMs in two distinct regions, which are characterized by different climatic conditions, to assess their influence on two potato varieties, namely Siena and Bellini. Inoculation with these strains, particularly the *Aureobasidium pullulans* strains Ach1-1 and Ach1-2, resulted in significant improvements in growth and yield. In 2018, impressive yields of 194.1 kg/0.05 ha and 186.6 kg/0.05 ha were recorded for the two strains, with the Ain Taoujdate site achieving yields of 157.1 kg/0.05 ha and 151.1 kg/0.05 ha for each of the two strains. Additionally, further observations revealed that the Siena variety is more susceptible to rot than the Bellini variety. However, Ach1-1 and Ach1-2 strains had a significant effect on this rot, showcasing their potential to mitigate this negative issue in the Bellini variety. These promising results underscore the potential of PGPMs to enhance potato production in the Fez–Meknes region of Morocco, contributing to global food security amid climate change.

Keywords: potato; PGPMs; *Aureobasidium pullulans*; agriculture; yield; sustainable agriculture

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1. Introduction

Climate change is significantly impacting agricultural systems worldwide due to its detrimental effects on crop health, particularly those due to elevated temperatures, extreme hot days, and shifts in precipitation patterns [1,2]. These climatic factors have become the primary drivers influencing agricultural practices across the globe [3]. Given the reliance of the agricultural sector on weather patterns, soil conditions, and irrigation, it is particularly vulnerable to climate change-induced phenomena, like droughts, heat stress, floods, rainfall variations, and extreme weather events [4–7]. As plants are stationary organisms, they must adapt to their specific habitats to survive. Therefore, implementing sustainable development strategies is crucial for mitigating the consequences of climate change on a global scale. Numerous studies highlight the significance of using climate-resilient practices that effectively address the challenges posed by changing climatic conditions [3].

Although potatoes (*Solanum tuberosum* L.) are a crop that can be irrigated and exhibit efficient water usage, as evidenced by a high harvest index [8], current potato cultivars display a heightened vulnerability to both drought and heat stress [9–11]. This cultivation has a significant position worldwide, being the fourth most important agronomic crop globally, following wheat, rice, and maize [12,13]. Together with sugar crops and cereals, potatoes represent one of the leading agricultural products in Morocco, with production amounting to around 1.6 million metric tons in 2021 [14]. The country annually dedicates an area ranging from 50,000 to 60,000 hectares to potato cultivation (1,707,068 metric tons), accounting for approximately 18 to 19% of the total cultivated vegetable crop area [15,16]. The average national yield stands at 29.67 metric tons per hectare [16].

To address the challenges posed by extreme climatic conditions and improve resource use efficiency, sustainable practices and environmentally friendly technologies are crucial [17]. These practices aim to enhance healthy food production, reduce unsustainable inputs, and improve soil health through measures such as sequestering soil carbon and maintaining soil organic matter and nutrient levels [18].

The application of beneficial microbes, particularly plant growth-promoting micro-organisms (PGPM), has been extensively studied with regard to their potential to improve crop growth and development [19–24]. They are micro-organisms that live in association with plant roots and can have beneficial effects on plant growth and health [19]. PGPMs can act in various ways, including by producing plant growth hormones, solubilizing soil nutrients, fixing atmospheric nitrogen, and protecting plants against diseases [25]. These rhizobacteria are often used as inoculants for agricultural crops to promote plant growth and reduce the use of chemical fertilizers, insecticides, and associated agrochemicals [26].

However, their implementation in the field remains limited [27]. Incorporating members of the phytomicrobiome into agricultural systems offers a sustainable approach to disease management and nutrient supplementation, reducing the negative impacts associated with excessive chemical inputs, like fertilizers and associated agrochemicals [27]. Additionally, phytomicrobiome members have proven to be effective in mitigating biotic and abiotic stresses that can hinder crop growth and production [20].

To investigate the effectiveness of these micro-organisms, our study aimed to screen the effects of different PGPM strains on potato cultivation under different climatic conditions by assessing the damaged potato tubers and examining the various agronomic characteristics of the potato varieties studied in two distinct regions of Morocco. We aimed to highlight the different cultivation factors of the potato by analyzing the data collected under different climatic conditions, in different localities, and for different varieties.

2. Materials and Methods

2.1. Study Site

The two experimental fields present contrasting climatic conditions. The Ain Taoujdate region in the Saïss Plain (Figure 1A) (33°55′50.2″ N 5°16′26.0″ W, altitude: 500 m) features a semi-arid Mediterranean climate, which is marked by consistently hot and dry summers and relatively cool winters, with annual temperatures ranging between 37 and 2.8 °C. On the other hand, the Lannoceur region located in the Middle Atlas Mountains (Figure 1B) (33°41′05.2″ N 4°51′19.9″ W, altitude: 1350 m) is set in stony hamri soil and has average rainfall of 500 mm. Its climatic profile encompasses notably colder winters and summers that, while still dry and experiencing high daytime temperatures, may have cooler periods or nights, with temperature extremes spanning from −7 to 40 °C.

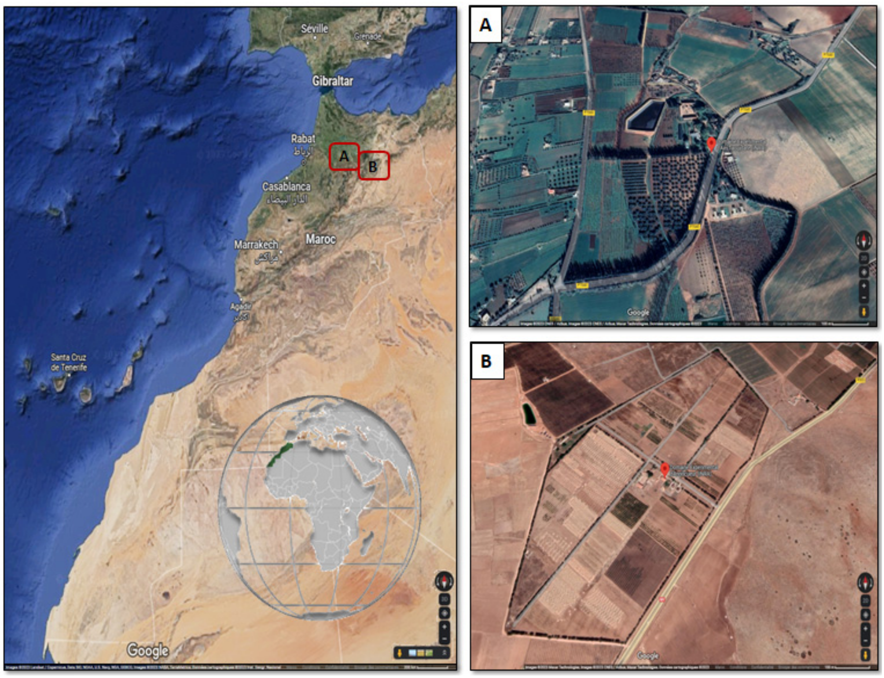

Figure 1. Experimental stations of the National Institute of Agricultural Research at the (**A**) Ain Taoujdate and (**B**) Lannoceur sites [28].

2.2. Plant Material

The potato cultivars, namely Siena and Bellini, used in the experiments were obtained from the University of Tuscia, Italy, in 2018. The potato tubers selected were free of wounds and rots and as homogeneous as possible in terms of size (50 and 100 mm in diameter). The varieties, namely Bellini and Siena, were chosen based on their unique attributes and the differing climates of our two experimental areas. The Bellini variety with pale yellow flesh was selected to be grown in Ain Taoujdate in the Saïss Plain due to its high yield and adaptability to the semi-arid Mediterranean climate. In contrast, the Siena variety with yellow flesh was chosen to be grown in Lannoceur in the Middle Atlas Mountains because of its resilience to fluctuating temperatures and potential fit to Moroccan climates. This pairing allowed us to explore potato cultivation in depth, advancing sustainable agriculture research.

2.3. Bacterial Strains and Culture Conditions

All of the eight PGPMs strains (Table 1) were obtained from the laboratory collection of Phytobacteriology and Biological Control at the National Institute of Agronomic Research in Meknes, Morocco. Our selection process was based on the strains' proven abilities to promote and protect other crops, as shown in previous studies [29–33]. PGPMs were cultured for 2 days at 28 °C using a YPGA medium (yeast extract, 5 g/L; peptone, 5 g/L; glucose, 10 g/L; agar, 15 g/L). Our large-scale bacterial production process involved culturing the bacteria in the fermenter (Bioengineering pilot 2-7/RALF, Bioengineering, Inc., Somerville, MA, USA) while maintaining precise control over culture parameters, including temperature, pH, dissolved oxygen, and agitation. Bacterial growth was continuously monitored, and concentration adjustments were made at optical density (OD_{600}) intervals using a spectrophotometer. Once the desired cell concentration, which was 10^8 CFU/mL, was achieved, the bacterial culture could be harvested for subsequent use, such as immersing tubers in baths containing the chosen bacterial suspension.

Table 1. Strains tested on potato tubers.

Strain Code	Specie	Origin	N2	PS	KS	ZnS	IAA	Sider	Reference
GAJ222	*Pseudomonas koreensis*	Rhizosphere of *Phoenix dactylifera*	+	+	−	+	++	++	[34]
GAB111	*Serratia nematodiphila*	Rhizosphere of *Phoenix dactylifera*	+	+	+	+	+	+	[34]
2066-7	*Pantoea agglomerans*	*Olea europea* (Picholine variety)	−	−	−	−	+	+	[32]
Ach1.1	*Aureobasidium pullulans*	Apple tree washing (var. Golden Delicious)	−	+	−	+	−	+	[35]
Ach1.2	*Aureobasidium pullulans*	Apple tree washing (var. Golden Delicious)	−	+	−	+	−	+	[35]
GLM10	*Klebsiella sp.*	Rhizosphere of *Phoenix dactylifera*	+	−	+	−	+	+	[34]
2332-A1	*Rahnella aquatilis*	Apple tree	+++	−	−	−	+++	−	[33]
2515-3	*Bacillus subtilis*	Apple tree	−	+	−	−	+	+	[33]

N2: non-symbiotic nitrogen fixation; PS, KS and ZnS: phosphorus, potassium, and zinc solubilization, respectively; Sider: siderophore production; IAA: 3-indol acetic acid production. (+++): high activity, (++): moderate activity, (+): low activity, and (−): non-detected activity.

2.4. Inoculum Preparation and Experimental Approach

In this study, the potato tubers underwent a pre-treatment process using the eight previously mentioned strains before being planted. In addition to the main treatments, two control groups were established: "Control+" and "Control−". The "Control+" group comprised potato tubers that were not inoculated with any of the tested strains but were given NPK fertilizer. However, the "Control−" group signified potato tubers that remained entirely untreated, with no exposure to biological agents or fertilizers. The treatment procedure involved immersing the tubers in a bucket filled with a suspension of each strain, which was prepared and adjusted to a concentration of 10^8 CFU/mL. Each strain was immersed for a duration of 30 min. Subsequently, the tubers were planted in rows using the conventional method to perform potato cultivation [36]. The potato plantations in Ain Taoujdate and Lannoceur were initiated on April 20th and May 28th, respectively.

The treatments in this study followed a randomized complete block design (RCBD) [37], which was arranged in a factorial arrangement with three replications. Each plot had a 0.05-hectare surface area and 30 blocks with dimensions of 3 m in terms width and 4 m in terms of length, resulting in a total area of 12 square meters in each block. The distance between the experimental blocks was 1 m. To perform planting, approximately 60 plants were placed in each block, with a distance of 70 cm between rows and individual plants. These planting distances aligned with the recommendations of the Ethiopian Institute of Agricultural Research [38].

The experimental plots received NPK fertilizer at specific rates (nitrogen: 150 units/ha; phosphorus: 165 units/ha; potassium: 175 units/ha), as recommended by the Ministry of Agriculture and Natural Resources [39]. Additionally, all other management practices, including weeding, hoeing, earthing up, and pest control, were uniformly implemented across all plots [40].

2.5. Data Collection

To assess the impacts of the eight PGPMs studied on potato cultivation at each experimental site, various parameters were taken into account. Measurements were taken for five randomly selected plants within the experimental plot when they were at a flowering rate of 50%. Plant height was measured from the soil surface to the tip of the main stem using a ruler. The number of stems originating from the mother tuber was recorded, along with the quantification of the leaves and leaflets. A chlorophyll meter (SPAD, Reference: 20210036_0042, Maximum size: 63.5 × 42.33 cm/300 dpi) was used to measure each plant's chlorophyll content. After harvesting, tubers were weighed using a balance, and their weights were recorded in terms of kilograms/plot (kg/0.05 ha). Tubers weighing 25 g or more, which were undamaged by mechanical factors, diseases, and pests, were considered to be marketable, while those weighing less than 25 g that were damaged or rotten were classified as non-marketable. The total tuber yield was calculated by combining the weights of marketable and non-marketable tubers [41]. Plant vigor was evaluated using a pre-defined scale. Measurements were made on a scale ranging from 1 to 5. Each value on this scale corresponded to a distinct degree of plant vitality. These assessments were entirely visual in nature, with a rating of 1 being assigned to plants with few or no leaves, and the scale progressively increased to 5, which denoted plants with leaves at their peak vigor.

2.6. Data Analysis

In this study, the agronomic data collected were analyzed using a multi-factor analysis of variance (ANOVA) via the statistical analysis software SPSS 21. This approach enabled the assessment of differences between various factors, including treatment, site, and variety. To determine statistical significance, a p-value of less than 0.05 was utilized as the threshold for interpreting the results. Additionally, these findings were analyzed through grouping using principal component analysis (PCA).

3. Results

3.1. Field Observation

According to field observations, the potato crop cycle varies between the two experimental fields. In the Ain Taoujdate site located in the heart of the Saïss plain, which was characterized by a semi-arid Mediterranean climate, the crop cycle is short (4 months, ranging from 20 April 2018 to 29 July 2018). In this zone, summers are hot and dry, winters are cool, and the average precipitation rate reaches 25.2 mm per trial period (Figure 2A). On the other hand, Lannoceur site located in the Middle Atlas Mountains, which was characterized by cold winters, dry summers, and high temperatures (average of 6.6 mm of precipitation per trial period), and the crop cycle was longer than that of the first experimental field (from 28 May 2018 to 26 September 2018) (Figure 2B).

According to the climatic conditions identified at the two stations, the phenological cycle of potatoes at Lannoceur exhibits a remarkably higher temperature than that of the site of Ain Taoujdate, especially during the elongation stage, and gradually decreases until the harvesting stage. As a result, the cycle at Lannoceur is longer than that at Ain Taoujdate. In contrast, the temperature at the Ain Taoujdate site shows variation, with an increase between the elongation and maturation stages, followed by a decrease at the harvesting stage, making the phenological cycle shorter at the Ain Taoujdate site that at the Lannoceur site.

Regarding precipitation at Lannoceur, it is significantly lower than that of the site of Ain Taoujdate, which influences the early stages of growth and potentially affects seed germination and initial plant development (planting and elongation). As the phenological cycle progresses towards the maturation and harvesting stages, precipitation levels at Lannoceur increase, providing potential moisture during these developmental stages, which increases the risk of rot compared to that recorded at Ain Taoujdate. This increase in precipitation at the Lannoceur site is primarily due to the mountainous thunderstorms that characterize in the region.

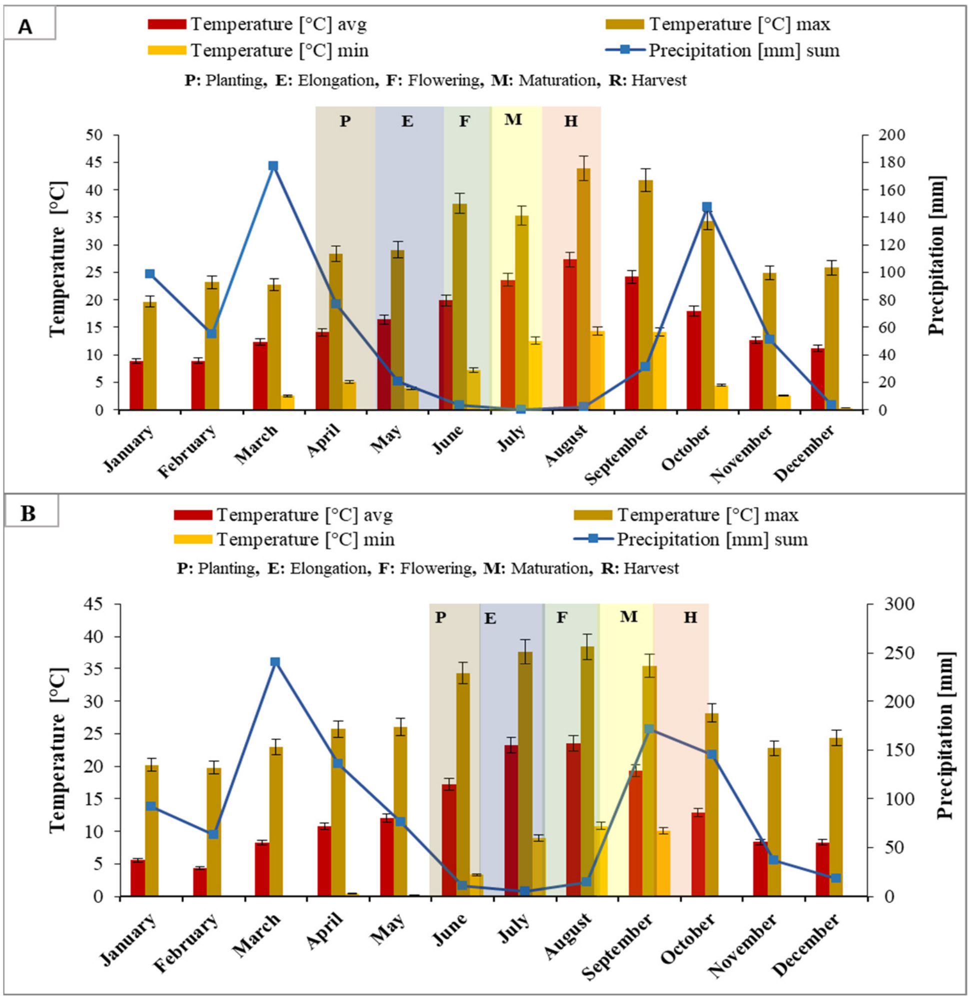

Figure 2. Climatic conditions in the 2018 agricultural campaign (**A**) at the Ain Taoujdate and (**B**) at Lannoceur sites.

3.2. Agronomic Parameters

Agronomic data, including measurements of plant vigor, height, the number of stems, the number of leaves, the number of leaflets, and chlorophyll content, were collected for both varieties of potatoes, namely Siena and Bellini, at the two experimental sites, namely Ain Taoujdate and Lannoceur (Figure 3). These measured parameters served as quantitative indicators of plant growth and their responses to applied treatments (Table S1). An increase in these values implies a positive effect, indicating that the treatment enhances plant growth.

The Ain Taoujdate site shows more vitality and branching than the Lannoceur site, with the Siena variety appearing to be more vigorous than the Bellini variety. Moreover, Ach1-1 and Ach1-2 strains exhibit notable results not only across the two sites, but also in both varieties. On average, Siena's vigor is measured as 4.3 ± 0.6 and 4 ± 0.6 for these strains, while for Bellini, it is measured as 3 ± 0.6 at the Ain Taoujdate site. At the Lannoceur site, these strains' results average out at 4 ± 0.6 and 3.7 ± 0.6 for the Siena variety and 3 ± 0.6 and 2.7 ± 0.6 for the Bellini variety. The strains GAJ222 and GAB111 also stand out, showing exceptionally high vigor at the Ain Taoujdate site compared to other strains.

Plant height and the number of stems, leaves, and leaflets rapidly increased before decreasing towards the end of this study in comparison to the Lannoceur site and the Bellini variety. These observations revealed variations in the proportion of height and the number of stems, leaves, and leaflets throughout the study period, encompassing the stages of plantation, elongation, flowering, maturation, and harvest. These variations can be partially attributed to plant defoliation during the agricultural campaign. Likewise, chlorophyll content exhibited a more remarkable development at the Ain Taoujdate site and in the Siena variety than at the Lannoceur site and in Bellini variety.

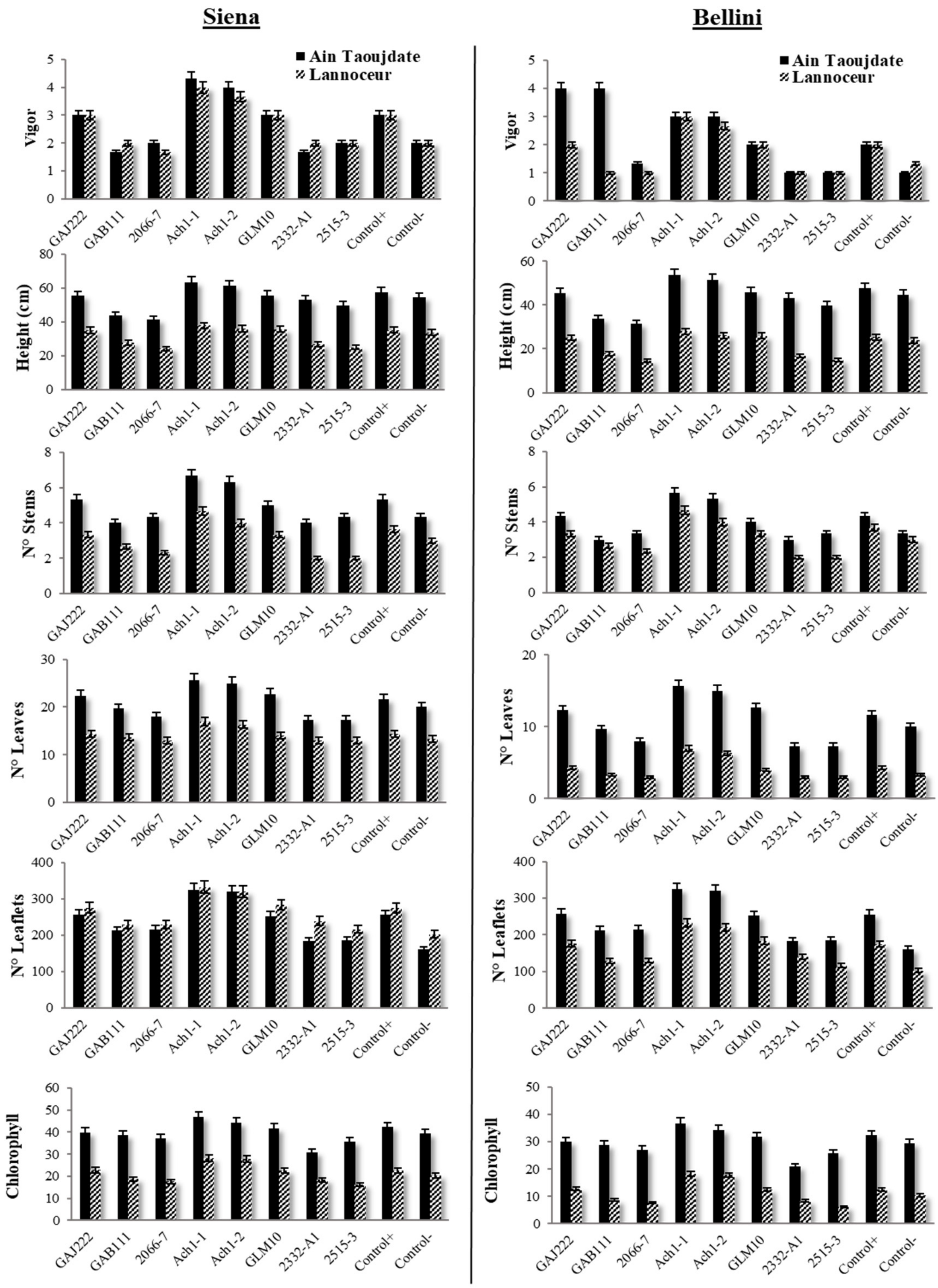

Figure 3. Agronomic parameters of the two potato varieties collected from the two sites—Control+: Strain-/NPK+; Control−: Strain-/NPK-.

Our results convincingly demonstrate that inoculation with PGPMs significantly stimulates the agronomic characteristics of potato tubers compared to the non-inoculated control group. The experimental results varied considerably between the different sites and potato varieties. The Ain Taoujdate site showed superior results to the Lannoceur site, and the Bellini variety outperformed the Siena variety.

The bacterial treatments Ach1-1 and Ach1-2 (*A. pullulans*) exhibited a remarkable increase, indicating the potential of these strains to improve plant growth and health. These strains produced remarkable results for all measured parameters (height; the number of stems, leaves, and leaflets; and chlorophyll content).

Inoculation using the two strains, namely Ach1-1 and Ach1-2 (*A. pullulans*), resulted in an observable growth in plant height compared to plants that were not inoculated. Specifically, for the Siena and Bellini varieties, the average heights identified at the Ain Taoujdate site were recorded as 63.7 ± 2.2 and 61.4 ± 2.2 and 53.7 ± 2.2 and 51.4 ± 2.2 respectively. On the other hand, at the Lannoceur site, the average heights were lower, with 37.9 ± 2.2 and 36.1 ± 2.2 recorded for the Siena variety and 27.9 ± 2.2 and 26.1 ± 2.2 recorded for the Bellini variety, respectively.

The data also demonstrated a correlation between leaf count and plant growth, with leaves being crucial for enabling photosynthesis and food production. More stems were found on both Siena and Bellini plants at the Ain Taoujdate site, ranging from 6.7 ± 0.9 and 6.3 ± 0.9 for Siena plants to 5.7 ± 0.9 and 5.3 ± 0.9 for Bellini plants. These values were slightly lower at the Lannoceur site, which had an average stem count of 4.35 ± 0.9 for both plant varieties. The average leaf count per plant at the Ain Taoujdate site was higher for the Siena variety (25.35 ± 1.3) than the Bellini variety (15.35 ± 1.3). In contrast, at the Lannoceur site, the Siena variety had an average of 16.65 ± 1.3 leaves, while the Bellini variety had a considerably lower leaf count of 6.65 ± 1.3. In terms of leaflets, both the Siena and Bellini varieties displayed an average count of 322.65 ± 21.5 at the Ain Taoujdate site. At the Lannoceur site, the Siena variety had slightly more leaflets (326 ± 21.5) than the Bellini variety (226.15 ± 21.5). For all treated potatoes, compared to the control group, a statistically significant increase (p-value < 0.001) was recorded (Table S2).

The results clearly show the beneficial impacts of the evaluated plant growth-promoting micro-organisms (PGPMs) on the tubers of both the Siena and Bellini varieties. Notably, the *A. pullulans* strains had a significant effect on the increase in the chlorophyll content. In the Ain Taoujdate location, we observed an increase of 45.6 ± 2.4 SPAD units for the Siena variety and 35.6 ± 2.4 SPAD units for the Bellini variety, while in the Lannoceur location, the increase was 28.05 ± 2.4 SPAD units for the Siena variety and 35.6 ± 2.4 SPAD units for the Bellini variety, with all measures being made in comparison to the control group. This outcome implies their ability to enhance photosynthesis and boost plant growth.

3.3. Biological Control and Effects of PGPMs on Yield and Damaged Tubers

The results obtained at the Ain Taoujdate site were particularly promising, revealing a significant increase in crop yield compared to the Lannoceur site and the Bellini variety.

The two specific bacterial strains, namely Ach1-1 and Ach1-2, notably enhanced the crop yield. Compared to the Lannoceur site and the Bellini variety, potatoes treated with these strains displayed a substantial increase in yield. The improvements were quantified with an average yield value of 19.45 ± 1.1 and 18.45 ± 1.1 for the Siena and Bellini varieties, respectively, at the Ain Taoujdate site. Meanwhile, at the Lannoceur site, the same strains resulted in an average yield of 13.3 ± 1.1 for the Siena variety and 12.3 ± 1.1 for the Bellini variety. These results clearly emphasize the effectiveness of PGPMs, especially *A. pullulans* strains, in terms of optimizing the growth and yield conditions of potato crops.

Furthermore, the study highlighted a remarkable effect of the *A. pullulans* strains, namely Ach1-1 and Ach1-2, in terms of protecting potato tubers against rot. In comparison to the control group that received no treatment, tubers treated with these strains showed a substantial decrease in the number of rot-affected tubers. Specifically, the decrease was 1.85 ± 1.1 for the Siena variety and 1 ± 1.1 for the Bellini variety at the Ain Taoujdate site, as well as 3.3 ± 1.1 for the Siena variety and 2.3 ± 1.1 for the Bellini variety at the Lannoceur site. This outcome demonstrates the effectiveness of PGPMs in terms of preventing fungal diseases and their beneficial roles in preserving the quality and health of potato crops (Figure 4 and Table 2).

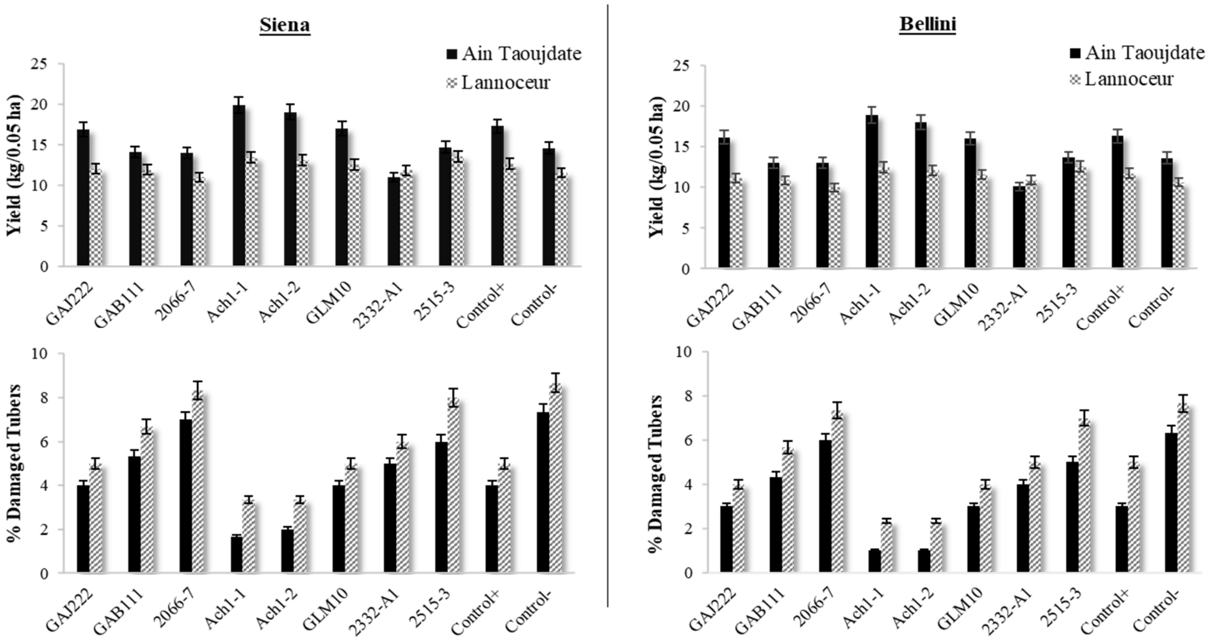

Figure 4. The effects of different strains on yield and damaged tubers for both potato varieties and at both sites—Control+: Strain-/NPK+; Control−: Strain-/NPK-.

Table 2. Analysis of variance (ANOVA) for yield and damaged tubers.

	Yield				Damaged Tubers			
	Type III SS	**ddl**	**D**	**Sig.**	**Type III SS**	**ddl**	**D**	**Sig.**
Site	364.705 ***	1	104.911	0.000	53.333 ***	1	15.348	0.000
Variety	29.008 **	1	8.345	0.005	26.133 **	1	7.520	0.008
Treatment	282.294 ***	9	9.023	0.000	386.467 ***	9	12.357	0.000
Site—Variety	0.000	1	0.000	0.992	0.033	1	0.010	0.922
Site—Treatment	134.043 ***	9	4.284	0.000	2.500	9	0.080	1.000
Variety—Treatment	0.103	9	0.003	1.000	0.700	9	0.022	1.000
Site—Variety—Treatment	0.038	9	0.001	1.000	0.800	9	0.026	1.000
Error	278.107	80			278.000	80		

, * Significance determined at p-value < 0.01 and p-value < 0.001, respectively.

The use of principal component analysis (PCA) allowed us to study the treatments, highlighting significant differences between them and revealing their distinct characteristics. As a statistical method, PCA was employed to reduce the dimensionality of the data while retaining the most important variations. This approach provided essential insights that enabled a better understanding of the impacts of different treatments throughout the study, as well as identifying distinct clusters in the space of principal components. These results contribute to a deeper understanding of the differences between treatments and open up new research perspectives.

However, at both sites, the treatments Ach1-1 and Ach1-2 prominently stand out as having higher yields (Figure 5A), suggesting their effectiveness in terms of promoting potato growth and development. These strains clearly exhibit advantages by promoting plant health, enhancing nutrient availability, and stimulating tuber growth. On the other hand, treatments 2066-7, 2332-A1, and 2515-3 and the control group (Figure 5B) showed less favorable results, with a higher percentage of damaged tubers, i.e., rot, and lower yields. These findings suggest that these treatments were less effective in terms of protecting potato tubers from damage, which could be attributed to various factors, such as unfavorable interactions with the soil, increased competition with other micro-organisms, or less active growth-promoting mechanisms.

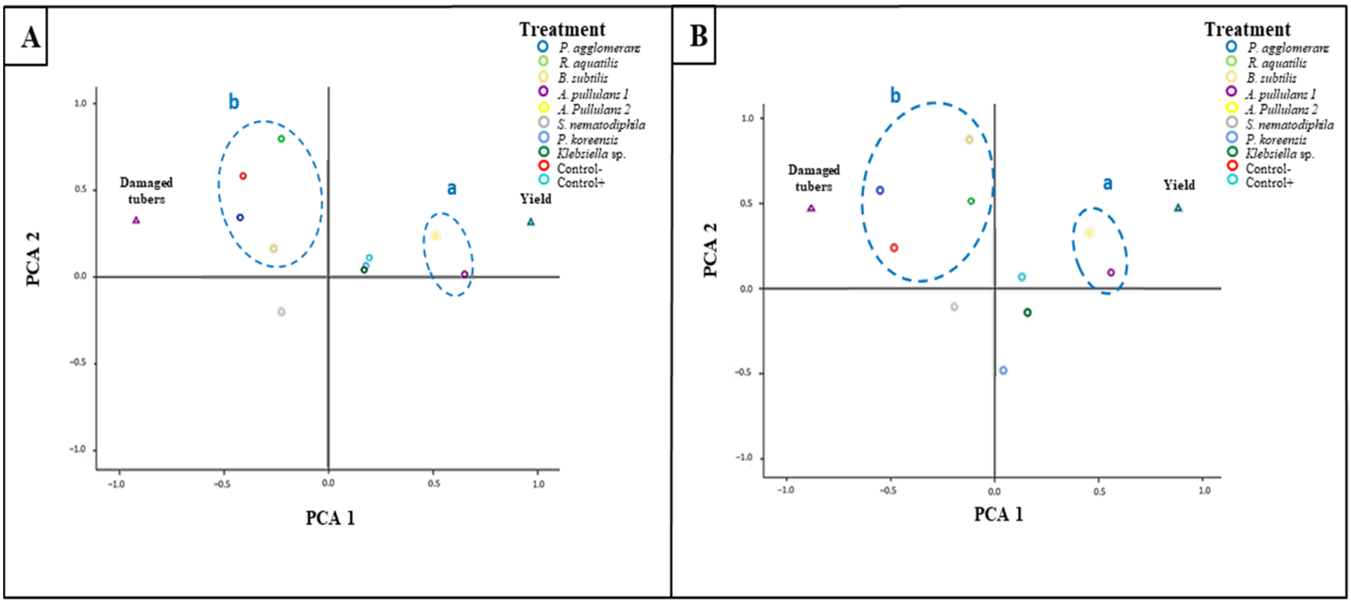

Figure 5. Classification of treatments according to yield and damaged tubers at two sites—(**A**): Ain-Taoujdate; (**B**): Lannoceur; (a): highest yield; (b): tubers severely damaged.

4. Discussion

The purpose of this study was to compare the levels of damaged tubers and assess the potential influence of environmental and management factors on potato decay in two different regions—Lannoceur and Ain Taoujdate—during the 2018 agricultural campaign. Additionally, we examined two distinct potato varieties, namely Bellini and Siena, to analyze the rate of exposure of potatoes to rot under the experimental conditions. Moreover, we evaluated the impacts of eight different strains on potatoes, considering various parameters.

Throughout the duration of the study, it was observed that the potato yield at the Ain Taoujdate site was significantly higher than that at the Lannoceur site. This variation in yield rate can be attributed to several factors, especially environmental conditions, such as temperature, humidity, and precipitation.

It is worth noting that during this agricultural campaign, the Lannoceur station received a higher average precipitation rate of 500 mm, whereas Ain Taoujdate received precipitation of 470 mm. This disparity in precipitation levels may have influenced the percentage of tuber damage, consequently influencing the observed variation in yield between the two sites.

Besides climatic conditions, soil composition also plays a crucial role in potato production and differs between locations [42–45]. A stony Hamri soil type characterizes the Lannoceur site, while the Ain Taoujdate site consists of clayey, limestone, and brown alluvial soils. This difference in soil composition may provide an explanation for the variation in yield between the two locations. According to the previous study findings, potato cultivation was greatly influenced by soil and climatic conditions, which had a significant impact on crop yields. This study revealed that potatoes displayed a preference for lighter soil types typically found at higher altitudes, where they received greater amounts of rainfall. Both temperature and precipitation were identified as crucial factors affecting potato yield formation, with precipitation having a greater impact than temperature [46]. Moreover, Karim et al.'s (2018) [47] findings contribute to our understanding of the complex relationship between climatic conditions, soil moisture, and potato yields. The study found that different climatic conditions could have a significant impact on potato yields. Under dry and normal conditions, potato yields were higher on terraced fields. In contrast, the yields were higher on non-terraced fields under wet conditions. The study also found that soil moisture content during the growing season is critically important to crop growth, and a lack of soil moisture in the early part of the growing season can negatively affect the number and size of potato tubers.

Research findings have emphasized the varying sensitivity of the Bellini potato variety compared to other potato varieties [48,49]. Throughout both sites, it was observed that the Siena variety exhibited a higher susceptibility to tuber damage than the Bellini variety. This discrepancy in susceptibility may be attributed to genetic variations between these two varieties. Additionally, the study's results emphasized the notable disparity in rot percentages observed between the Ain Taoujdate and Lannoceur sites.

The results reported by Tsror et al. (2012) [50] revealed significant differences in the proportion of decayed tissue observed in infected tubers between various potato cultivars. Among the cultivars tested, Bellini exhibited a comparatively lower level of tuber deterioration. These results are consistent with the results reported by Adesemoye and Kloepper (2009) [51], who documented a moderate incidence of disease in the Bellini potato variety.

Microbial inoculants offer promising solutions to agro-environmental challenges, as they have the ability to stimulate plant growth, enhance nutrient availability and uptake, and promote overall plant health [52].

Our study demonstrated that the Ach1-1 and Ach1-2 strains effectively enhanced the yield of the samples, outperforming the other treatments. The positive effects of these strains can be attributed to mechanisms such as increased nitrogen fixation, improved phosphorus solubilization, growth-promoting hormone synthesis, or the suppression of pathogens. Previous research has already recognized the potential of *A. pullulans*, which is a yeast-like fungus, as a biofertilizer due to its ability to promote plant growth [53]. In their study, Kour et al. (2019) [54] explored the capacity of *A. pullulans* to improve plant growth and highlighted inter-strain variability in its plant growth-promoting traits. Furthermore, Achbani et al., 2005 [55] evaluated the capacity of various plant growth-promoting rhizobacteria genera and found a remarkable ability in phosphate solubilization, highlighting their potential to improve soil fertility and plant growth. *A. pullulans* has exhibited a remarkable antagonistic potential, displaying a protective effect surpassing 90% against diverse pathogens, including soft rot [56,57]. Furthermore, extensive research has revealed that strains of *A. pullulans* have shown robust antagonistic behaviors, effectively protecting against crucial post-harvest pathogens on various other crops [58–62].

This study's outcomes underscore the promising possibilities associated with the various strains tested. Strains GAJ222 and GLM10 also displayed remarkable efficacy across the board, as measured based on various agronomic parameters. This approach included an enhancement in plant vigor, an increase in the plant's overall height, and an increase in the number of both stems and leaves, along with their leaflets. However, the demonstrated potency of these strains goes beyond these primary growth characteristics. It also significantly boosts the yield of potato crops and, most importantly, offers a layer of protection against decay, thus safeguarding the produce's quality and longevity.

Plant growth-promoting micro-organisms (PGPMs), including those found within the genera *Pseudomonas*, and *Klebsiella*, are known for their dual functionality. They not only stimulate plant growth, but also act as natural protectors against plant diseases [63–68].

Numerous studies have provided compelling evidence of *Pseudomonas*' abilities in terms of promoting plant growth. This versatile micro-organism exhibits a number of advantageous traits, including the ability to break down vital nutrients, like phosphorus, potassium, and nitrogen, thus making them more accessible to plants. Additionally, *Pseudomonas* can synthesize antibacterial substances, such as antibiotics, extracellular hydrolases, and a range of secondary metabolites [69–72]. These attributes play crucial roles in bolstering the plant's defense mechanisms, effectively shielding it from the harmful impacts of pathogenic bacteria [73]. The subgroup *P. koreensis* may exhibit fewer biocontrol properties than other strains, but it is uniquely characterized with a rich assortment of phytostimulatory attributes. These attributes include the modulation of plant hormones and a pronounced ability to enhance plant nutrition [74,75].

5. Conclusions

In conclusion, this study has highlighted yield variations between the sites, highlighting the influence of site-specific factors on potato productivity. Additionally, this study emphasized the importance of considering variability when assessing the impacts of bacterial treatments. Strains Ach1-1 and Ach1-2 (*Aureobasidium pullulans*) have shown promising potential to improve potato yield. Furthermore, the variation in the percentage of damaged tubers between the two potato varieties indicates the involvement of other factors beyond PGPM treatments. However, further research is needed to understand and elucidate the underlying mechanisms of the efficacy of these bacteria. Investigating the differential sensitivities of the Bellini and Siena varieties to rot and studying the impacts of biological treatments on their incidence would also be valuable for potato disease management.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/microbiolres14040141/s1, Table S1. Mean values of agronomic parameters with corresponding standard errors for each treatment; Table S2. Analysis of variance (ANOVA) for all agronomic parameters.

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References

1. Rising, J.; Devineni, N. Crop switching reduces agricultural losses from climate change in the United States by half under. *Nat. Commun.* **2020**, *11*, 4991. [CrossRef] [PubMed]
2. Camaille, M.; Fabre, N.; Clément, C.; Barka, E.A. Advances in wheat physiology in response to drought and the role of plant growth promoting rhizobacteria to trigger drought tolerance. *Microorganisms* **2021**, *9*, 687. [CrossRef] [PubMed]
3. Pereira, L. *Climate Change Impacts on Agriculture across Africa*; Oxford University Press: Oxford, UK, 2017. [CrossRef]
4. Rymuza, K.; Radzka, E.; Lenartowicz, T. Influence of weather conditions on early potato yields in east-central Poland. *Commun. Biometry Crop Sci.* **2015**, *10*, 65–72. [CrossRef]
5. Shimoda, S.; Kanno, H.; Hirota, T. Analysis of temperature and rainfall-based weather patterns showing significant correlations between climatic shifts and potato yield trends in Japan. *Agric. For. Meteorol.* **2018**, *263*, 147–155. [CrossRef]
6. Dhankher, O.P.; Foyer, C.H. The role of climate-resilient crops in enhancing global food security and safety. *Plant Cell Environ.* **2018**, *41*, 877–884. [CrossRef]
7. Srivastav, A.L.; Dhyani, R.; Ranjan, M.; Madhav, S.; Sillanpää, M. Strategies for climate-resilient sustainable management of water resources and agriculture. *Environ. Sci. Pollut. Res.* **2021**, *28*, 41576–41595. [CrossRef]
8. Vos, J.; Haverkort, A.J. Water availability and potato crop performance. In *Potato Biology and Biotechnology*; Elsevier: Amsterdam, The Netherlands, 2007; pp. 333–351. [CrossRef]
9. Iwama, K.; Yamaguchi, J. Abiotic stresses. In *Handbook of Potato Production, Improvement, and Postharvest Management*; CRC: Boca Raton, FL, USA, 2006; pp. 231–278. [CrossRef]

10. Levy, D.; Veilleux, R.E. Adaptation of potato to high temperatures and salinity—A review. *Am. J. Potato Res.* **2007**, *84*, 487–506. [CrossRef]
11. Levy, D.; Coleman, W.K.; Veilleux, R.E. Adaptation of potato to water shortage: Irrigation management and enhancement of tolerance to drought and salinity. *Am. J. Potato Res.* **2013**, *90*, 186–206. [CrossRef]
12. Sampaio, S.L.; Petropoulos, S.A.; Alexopoulos, A.; Heleno, S.A.; Santos-Buelga, C.; Barros, L.; Ferreira, I.C.F.R. Potato peels as sources of functional compounds for the food industry: A review. *Trends Food Sci.* **2020**, *103*, 118–129. [CrossRef]
13. Sookhtanlou, M.; Allahyari, M.S.; Surujlal, J. Health Risk of Potato Farmers Exposed to Overuse of Chemical Pesticides in Iran. *Saf. Health Work* **2022**, *13*, 23–31. [CrossRef]
14. Saifaddin, G. Agricultural Land Area in Morocco in 2021, by Selected Crop Type (in Hectares), Published in 26 April 2023, Statista Data. Available online: https://www.statista.com/statistics/1302523/agricultural-area-in-morocco-by-crop-type/ (accessed on 26 April 2023).
15. Alaoui, K.; Chafik, Z.; Arabi, M.; Abouloifa, H.; Asehraou, A.; Chaoui, J.; Kharmach, E.-Z. In vitro antifungal activity of *Lactobacillus* against potato Late blight *Phytophthora infestans*. *Mater. Today Proc.* **2021**, *45*, 7725–7733. [CrossRef]
16. FAO (Food and Agriculture Organization of the United Nations), 2022. FAOSTAT-Crops and Livestock Products. Latest Update: 17 February 2022. Available online: https://www.fao.org/faostat/en/#data/QCL (accessed on 23 May 2023).
17. Pareek, A.; Dhankher, O.P.; Foyer, C.H. Mitigating the impact of climate change on plant productivity and ecosystem sustainability. *J. Exp. Bot.* **2020**, *71*, 451–456. [CrossRef] [PubMed]
18. Drost, S.M.; Rutgers, M.; Wouterse, M.; De Boer, W.; Bodelier, P.L. Decomposition of mixtures of cover crop residues increases microbial functional diversity. *Geoderma* **2020**, *361*, 114060. [CrossRef]
19. Mehnaz, S.; Lazarovits, G. Harnessing the power of Plant Growth-Promoting Rhizobacteria for sustainable agriculture. *Plant Biotechnol. J.* **2021**, *19*, 179–183. [CrossRef]
20. Khan, N.; Bano, A.; Ali, S.; Babar, M.A. Crosstalk amongst phytohormones from planta and PGPR under biotic and abiotic stresses. *Plant Growth Regul.* **2020**, *90*, 189–203. [CrossRef]
21. Zhou, C.; Zhu, L.; Xie, Y.; Li, F.; Xiao, X.; Ma, Z. *Bacillus licheniformis* SA03 Confers increased saline–alkaline tolerance in *Chrysanthemum* plants by induction of abscisic acid accumulation. *Front. Plant Sci.* **2017**, *8*, 1143. [CrossRef]
22. Cordero, I.; Balaguer, L.; Rincón, A.; Pueyo, J.J. Inoculation of tomato plants with selected PGPR represents a feasible alternative to chemical fertilization under salt stress. *J. Plant Nutr. Soil Sci.* **2018**, *181*, 694–703. [CrossRef]
23. Dodd, I.C.; Zinovkina, N.Y.; Safronova, V.I.; Belimov, A.A. Rhizobacterial mediation of plant hormone status. *Ann. Appl. Biol.* **2010**, *157*, 361–379. [CrossRef]
24. Egamberdieva, D.; Wirth, S.J.; Alqarawi, A.A.; Abd_Allah, E.F.; Hashem, A. Phytohormones and beneficial microbes: Essential components for plants to balance stress and fitness. *Front. Microbiol.* **2017**, *8*, 2104. [CrossRef]
25. Sheng, Y.; Li, J.; Liu, X.; Gopalakrishnan, S.; Arias, R.S.; Xie, L.; Zhang, Y. Rhizobacteria Inoculants as a Sustainable Tool to Improve Potato Crop Production in a Semi-Arid Environment. *Sustainability* **2021**, *12*, 2828. [CrossRef]
26. Gouda, M.H.B.; Zhang, C.; Peng, S.; Kong, X.; Chen, Y.; Li, H.; Yu, L. Combination of sodium alginate-based coating with L-cysteine and citric acid extends the shelf-life of fresh-cut lotus root slices by inhibiting browning and microbial growth. *Postharvest Biol. Technol.* **2021**, *175*, 111502. [CrossRef]
27. Antar, M.; Lyu, D.; Nazari, M.; Shah, A.; Zhou, X.; Smith, D.L. Biomass for a sustainable bioeconomy: An overview of world biomass production and utilization. *Renew. Sustain. Energy Rev.* **2021**, *139*, 110691. [CrossRef]
28. Google-Earth. Available online: https://www.google.com/intl/fr/earth/ (accessed on 31 March 2021).
29. Badri, H.; Achbani, E.H.; Jijakli, H. *Aureobasidium pullulans* strain Ach1-1 a biocontrol of postharvest diseases of apples: 15 crucial years of research before starting commercial development. In Proceedings of the International Symposium on Crop Protection, Ghent, Belgium, 22 May 2018.
30. Ameur, A.; Rhallabi, N.; Doussomo, M.E.; Benbouazza, A.; Ennaji, M.M.; Achbani, E. Selection and efficacy biocontrol agents in vitro against fire blight (*Erwinia amylovora*) of the rosacea. *Int. Res. J. Eng. Technol.* **2017**, *4*, 539–545.
31. Haggoud, A.; Benbouaza, A.; Bouaichi, A.; Achbani, E.H. Plant growth promotion and bacterial canker control of *Lycopersicon esculentum* L. cv. Campbell 33 by biocontrol agents. *J. Crop Prot.* **2017**, *6*, 235–244.
32. Sadik, S.; Mazouz, H.; Benbouazza, A.B.A.; Achbani, E.H. Biological control of bacterial onion diseases using a bacterium, *Pantoea agglomerans* 2066-7. *Int. J. Sci. Res.* **2015**, *4*, 103–111.
33. Habbadi, K.; Benkirane, R.; Benbouazza, A.; Bouaichi, A.; Maafa, I.; Chapulliot, D.; Achbani, E.H. Biological control of grapevine crown gall caused by *Allorhizobium vitis* using bacterial antagonists. *Int. J. Sci. Res.* **2017**, *6*, 1390–1397.
34. Mohamed, O.Z.; Symanczik, S.; El Kinany, S.; Larbi, A.Z.I.Z.; Fagroud, M.; Abidar, A.; Bouamri, R. Effect of PGPR and mixed cropping on mycorrhizal status, soil fertility, and date palm productivity under organic farming system. *Org. Agric.* 2023, *under review*. [CrossRef]
35. Achbani, E.H.; Mounir, R.; El Jaafari, S.; Douira, A.; Benbouazza, A.; Jijakli, H. Selection of antagonists of postharvest apple parasites: *Penicillium expansum* and *Botrytis cinerea*. *Commun. Agric. Appl. Biol. Sci.* **2005**, *70*, 143–149.
36. Chamkhi, I.; Sbabou, L.; Aurag, J. Improved growth and quality of saffron (*Crocus sativus* L.) in field conditions through inoculation with selected native plant growth-promoting rhizobacteria (PGPR). *Ind. Crop. Prod.* **2023**, *197*, 116606. [CrossRef]
37. Neelam, A.; Sharma, P.; Saini, R. Effects of planting methods on growth, yield and economics of potato (*Solanum tuberosum* L.) in hills of Uttarakhand. *Indian J. Agron.* **2018**, *63*, 315–318. [CrossRef]

38. Bhatti, A.M.; Khan, I. Application of Randomized Complete Block Design in the design of experiments. *Int. J. Soc. Sci. Hum. Rev.* **2021**, *11*, 75–84.
39. MoANR, Ministry of Agriculture and Natural Resource. Addis Ababa, Ethiopia. Plant Variety Release, Protection and Seed Quality Control Directorate. *Crop Var.* **2016**, *19*, 178.
40. EIAR, Ethiopian Institute of Agricultural Research. *Crop Technologies Guideline*; Ethiopian Institute of Agricultural Research: Addis Ababa, Ethiopia, 2007; Volume 173.
41. Abebe, T.; Wongchaochant, S.; Taychasinpitak, T. Evaluation of specific gravity of potato varieties in Ethiopia as criterion for determining processing quality. *Kasetsart J. Nat. Sci.* **2013**, *47*, 30–41.
42. Díaz-Barradas, M.C.; Gallego-Fernández, J.B.; Zunzunegui, M. Plant response to water stress of native and non-native *Oenothera drummondii* populations. *Plant Physiol. Biochem.* **2020**, *154*, 219–228. [CrossRef] [PubMed]
43. Russo, S.; Dosio, A.; Graversen, R.G.; Sillmann, J.; Carrao, H.; Dunbar, M.B.; Singleton, A.; Montagna, P.; Barbola, P.; Vogt, J.V. Magnitude of extreme heat waves in present climate and their projection in a warming world. *J. Geophys. Res. Atmos.* **2014**, *119*, 12500–12512. [CrossRef]
44. Perkins-Kirkpatrick, S.E.; Lewis, S.C. Increasing trends in regional heatwaves. *Nat. Commun.* **2020**, *11*, 3357. [CrossRef]
45. Hlisnikovský, L.; Menšík, L.; Kunzová, E. The effect of soil-climate conditions, farmyard manure and mineral fertilizers on potato yield and soil chemical parameters. *Plants* **2021**, *10*, 2473. [CrossRef]
46. Liang, K.; Qi, J.; Liu, E.Y.; Jiang, Y.; Li, S.; Meng, F.R. Estimated potential impacts of soil and water conservation terraces on potato yields under different climate conditions. *JSWC* **2019**, *74*, 225–234. [CrossRef]
47. Karim, Z.; Hossain, M.S. Management of bacterial wilt (*Ralstonia solanacearum*) of potato: Focus on natural bioactive compounds. *J. Biodiver. Conserv. Bioresour. Manag.* **2018**, *4*, 73–92. [CrossRef]
48. Mahfouze, H.A.; Ahmed, H.Z.; El-Sayed, O.E. Gene expression of pathogenesis-related proteins and isozymes in potato varieties resistant and susceptible to late blight disease. *Int. J. Agric. Biol.* **2021**, *26*, 490–498. [CrossRef]
49. Daami-Remadi, M.; Jabnoun-Khiareddine, H.; Sdiri, A.; El Mahjoub, M. Comparative reaction of potato cultivars to *Sclerotium rolfsii* assessed by stem rot and tuber decay severity. *Pest Technol.* **2012**, *6*, 54–59. [CrossRef]
50. Tsror, L.; Erlich, O.; Hazanovsky, M.; Ben Daniel, B.; Zig, U.; Lebiush, S. Detection of Dickeya spp. latent infection in potato seed tubers using PCR or ELISA and correlation with disease incidence in commercial field crops under hot-climate conditions. *Plant Pathol.* **2012**, *61*, 161–168. [CrossRef]
51. Adesemoye, A.O.; Kloepper, J.W. Plant–microbes interactions in enhanced fertilizer-use efficiency. *Appl. Microbiol. Biotechnol.* **2009**, *85*, 1–12. [CrossRef] [PubMed]
52. Fu, S.F.; Sun, P.F.; Lu, H.Y.; Wei, J.Y.; Xiao, H.S.; Fang, W.T.; Cheng, B.Y.; Chou, J.Y. Plant growth-promoting traits of yeasts isolated from the phyllosphere and rhizosphere of *Drosera spatulata* Lab. *Fungal Biol.* **2016**, *120*, 433–448. [CrossRef]
53. Sun, P.F.; Chien, I.A.; Xiao, H.S.; Fang, W.T.; Hsu, C.H.; Chou, J.Y. Intra specific variation in plant growth-promoting traits of *Aureobasidium pullulans*. *Chiang Mai J. Sci.* **2019**, *46*, 15–31.
54. Kour, D.; Rana, K.L.; Yadav, N.; Yadav, A.N. Bioprospecting of phosphorus solubilizing bacteria from Renuka Lake ecosystems, lesser Himalayas. *J. Appl. Biol. Biotechnol.* **2019**, *7*, 1–6. [CrossRef]
55. Achbani, E.H.; Mounir, R.; Jaafari, S.; Douira, A.; Benbouazza, A.; Jiakli, M.H. La sélection des antagonistes de *Penicillium expansum* et *Botrytis cinerea*, deux parasites de post-récolte des pommes. *Al AWAMIA* **2006**, *4*, 4–16.
56. Krimi Bencheqroun, S.; Bajji, M.; Massart, S.; Bentata, F.; Labhilili, M.; Achbani, H.; El Jaafari, S.; Jijakli, M.H. Biocontrol of Blue Mold on Apple Fruits by *Aureobasidium Pullulans* (Strain Ach1-1): In Vitro and In Situ Evidence for The Possible Involvement of Competition for Nutrients. *Comm. Appl. Biol. Sci.* **2006**, *71*, 1151–1157.
57. Adikaram, N.K.B.; Joyce, D.C.; Terry, L.A. Biocontrol activity and induced resistance as a possible mode of action for *Aureobasidium pullulans* against grey mould of strawberry fruit. *Australas. Plant Pathol.* **2002**, *31*, 223–229. [CrossRef]
58. Castoria, R.; De Curtis, F.; Lima, G.; Caputo, L.; Pacifio, S.; De Cicco, V. *Aureobasidium pullulans* (LS30) an antagonist of postharvest pathogens of fruits: Study on its mode of action. *Postharvest Biol. Technol.* **2001**, *22*, 7–17. [CrossRef]
59. Ippolito, A.; El Ghaouth, A.; Wilson, C.L.; Wisniewski, M. Control of postharvest decay of apple fruit by *Aureobasidium pullulans* and induction of defense responses. *Postharvest Biol. Technol.* **2000**, *19*, 265–272. [CrossRef]
60. Janisiewicz, W.J.; Tworkoski, T.J.; Sharer, C. Characterizing the mechanism of biological control of postharvest diseases on fruits with a simple method to study competition for nutrients. *Phytopathology* **2000**, *90*, 1196–1200. [CrossRef] [PubMed]
61. Kunz, S.; Schmitt, A.; Haug, P. Development of strategies for fire blight control in organic fruit growing. Integrated Plant Protection in Fruit Crops Subgroup Pome Fruit Diseases. *IOBC-WPRS Bull.* **2012**, *84*, 71–78.
62. Lima, G.; Arru, S.; De Curtis, F.; Arras, G. Influence of antagonist, host fruit and pathogen on the biological control of postharvest fungal diseases by yeasts. *J. Ind. Microbio. Biotech.* **1999**, *23*, 223–229. [CrossRef]
63. Schena, L.; Nigro, F.; Pentimone, I.; Ligoria, A.; Ippolito, A. Control of postharvest rots of sweet cherries and table grapes with endophytic isolates of *Aureobasidium pullulans*. *Postharvest Biol. Technol.* **2003**, *30*, 209–220. [CrossRef]
64. Glick, B.R.; Penrose, D.M.; Li, J. A model for the lowering of plant ethylene concentrations by plant growth-promoting bacteria. *J. Theor. Biol.* **1998**, *190*, 63–68. [CrossRef] [PubMed]
65. Shaharoona, B.; Jamro, G.M.; Zahir, Z.A.; Arshad, M.; Memon, K.S. Evaluating the efficacy of various *Pseudomonas* spp. and *Burkholderia caryophylli* containing ACC-deaminase in enhancing growth and yield of wheat (*Triticum aestivum* L.). *J. Microbiol. Biotechnol.* **2007**, *17*, 1300–1307.

66. Liu, Y.; Wang, H.; Sun, X.; Yang, H.; Wang, Y.; Song, W. Research on colonization mechanisms of nitrogen-fixing PGPB, *Klebsiella pneumoniae* NG14 on the root surface of rice and biofilm formation. *Curr. Microbiol.* **2011**, *62*, 1113–1122. [CrossRef]
67. Mazumdar, D.; Saha, S.P.; Ghosh, S. Isolation of potent PGPR *Klebsiella pneumoniae* rs26 from the rhizosphere of chickpea (*Cicer arietinum*). *J. Pharm. Innov.* **2018**, *7*, 56–62.
68. Dey, S.; Dutta, P.; Majumdar, S. Biological control of *Macrophomina phaseolina* in *Vigna mungo* L. through the use of endophytic *Klebsiella pneumoniae* HR1. *Jordan J. Biol. Sci.* **2019**, *12*, 219–227.
69. Zhang, M.; Zhang, C.; Zhang, S.; Yu, H.; Pan, H.; Zhang, H. Promoting maize growth and resistance to northern corn leaf blight with *Klebsiella jilinsis* 2N3. *Biol. Control* **2021**, *156*, 104554. [CrossRef]
70. Cook, R.J. Enhancing the utility of introduced microorganisms for biological control of plant pathogens. *Annu. Rev. Phytopathol.* **1993**, *31*, 53–80. [CrossRef] [PubMed]
71. Haas, D.; Défago, G. Biological control of soil-borne pathogens by fluorescent pseudomonads. *Nat. Rev. Microbiol.* **2005**, *3*, 307–319. [CrossRef] [PubMed]
72. Mercado-Blanco, J. Biocontrol properties of *Pseudomonas* strains against plant pathogens. In *Pseudomonas: New Aspects of Pseudomonas Biology*; Ramos, J.-L., Goldberg, J.B., Filloux, A., Eds.; Springer: Dordrecht, The Netherlands, 2015; Volume 7, pp. 121–172. [CrossRef]
73. Olorunleke, F.E.; Kieu, N.P.; Höfte, M.; Kieu Phuong, N.; Höfte, M. Advances in Pseudomonas biocontrol. In *Bacteria-Plant Interactions: Advanced Research and Future Trends*; Murillo, J., Vinatzer, B.A., Jackson, R.W., Arnold, D.L., Eds.; Caister Academic Press: Wymondham, UK, 2015; pp. 167–198. [CrossRef]
74. Müller, T.; Behrendt, U. Harnessing the biocontrol potential of plant-associated pseudomonads—Towards pesticide-free agriculture? *Biol. Control* **2021**, *155*, 104538. [CrossRef]
75. Vacheron, J.; Moënne-Loccoz, Y.; Dubost, A.; Gonçalves-Martins, M.; Muller, D.; Prigent-Combaret, C. Fluorescent *Pseudomonas* strains with limited plant beneficial properties are favored in the maize rhizosphere. *Front. Plant Sci.* **2016**, *7*, 1212. [CrossRef]